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Effect of Room Illuminance on Monitor Black Level Luminance and Monitor Calibration

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In this article we demonstrate the effect of room illuminance and surrounding monitor black level luminance on image quality for soft copy interpretation. Luminance values of a 10% central target and image quality evaluations and observer performance using a contrast-detail mammography (CDMAM) phantom demonstrate these effects. Our results indicate that high room illuminance has a more damaging effect on image quality when the surrounding monitor luminance is 0% to 5% of the maximum monitor luminance. The effect of room illuminance is less obvious when the surrounding monitor luminance is 20% of the maximum.

KEY WORDS: Black level, luminance, illuminance, image contrast, diffuse reflection, image surround

EFFECTS OF AMBIENT room light, diffuse and specular reflections, and veiling glare are often ignored in diagnostic radiology when soft copy is read for image interpretation. These are, however, very important factors that must be considered to ensure proper image interpretation. With increasing use of full field digital mammography (FFDM) and soft copy display systems, these parameters must be carefully controlled for diagnostic accuracy. Under the Mammography Quality Standards Act (MQSA), all FFDM manufacturers seeking approval for marketing their soft copy image interpretation systems are required to provide display system quality control (QC) criteria and ambient room light requirements. It is very important that the radiology facilities follow these QC requirements. It is also important that, once the monitor calibrations are established, the facilities maintain the integrity of the set-up.

In our ongoing efforts[2,3,31] to demonstrate the importance of proper viewing conditions for image interpretation, we have studied the effect of room illuminance and monitor surround luminance on image quality. It is obvious that image contrast decreases as the black level luminance is increased due to diffuse reflection of ambient room light from the monitors. AAPM Task Group18[4], (TG 18) recommends that room illuminance (I) be restricted to $I \leq (0.25\ L_{min})/R_d$, where L_{min} is minimum dark level luminance and R_d is the diffuse reflection coefficient in units of cd/m^2/lux. However, TG 18 does not provide any specific recommendations for appropriate luminance for the image surround (which in this article we call *surrounding monitor luminance*, for simplicity's sale). DICOM (Digital Imaging and Communication in Medicine)[5] Part 14 recommends that surrounding monitor luminescence be 20% of the maximum monitor luminance when a DICOM calibration is performed. Several studies[6-12]

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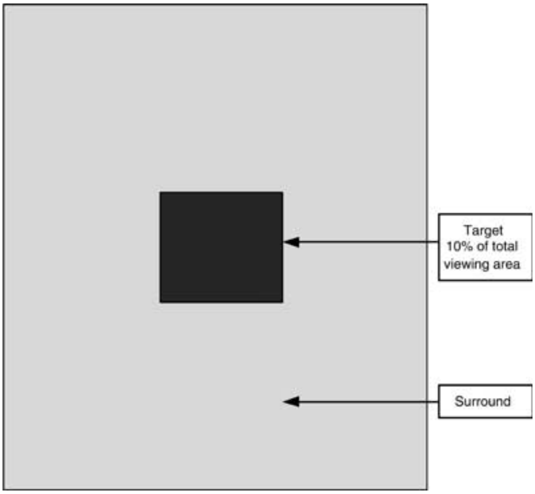

Fig 1. Experimental set up for observations of Black Target Luminace. The Black Target Luminace, which is 10% of the viewing area, was measured as room illuminance and surround were changed.

have investigated the effects of the ambient light and image surround intensity on the display luminance and image contrast. Mertelmeier[11] believes that room lighting affects the contrast threshold more severely at low background levels than at high background levels. According to Cederberg et al[12], however, background lighting does not appear to seriously affect the reader's ability to detect lesions.

We have observed that a change in room light from 0 to 50 lux with 0%–5% surrounding monitor luminance has a much more drastic effect on image quality than the same change of room illuminance when the surround is 15%–20%. In this study we examined this demonstrated effect quantitatively using a contrast-detail phantom.

EXPERIMENTAL METHODS

Room illuminance (in lux) was measured at eye level using both an UNFORS Instruments illuminance meter and an International Light illuminance meter. The nine different illuminance levels, 0, 1, 2, 5, 10, 20, 30, 40, and 50 lux, used in this study were measured with both meters. We then varied surrounding monitor luminance from 0% to 20% of the maximum. The luminance (cd/m^2) of the central square was measured with two Minolta spot meters, models LS-100a and LS-110, for each of the nine illuminance levels when surround levels were varied as 0%, 5%, 10%, and 20% of of the maximum monitor luminance of 240 cd/m^2. The LS-100a and LS-110 spot meters provide measurement angles of 1° and 0.33°, respectively. The central region measured was selected to be 10% of the total monitor viewing area. A contrast-detail mammography (CDMAM) phantom was used to detect degradation in image contrast involving variations of monitor surround luminance and room illuminance. This Phantom has six, 1 cm Lucite sheets with contrast detail inserts as (1) 15 cm × 23 cm × 0.5 mm aluminum plate and (2) 205 cells, each with two gold disks. The disk diameters are logarithmically scaled from 0.10 to 0.80 mm, and disk thickness is scaled from 0.05 to 1.6 μm. The product of diameter and thickness for disks (K value) in the same column is the same.

RESULTS AND DISCUSSION

To evaluate the effect of diffuse reflection on image luminance, a test pattern consisting of a central square of 0% luminance and a surround area of variable luminance was used. Figure 1 shows the display layout. The target square, centrally located on the monitor display, was 10% of the display area. The luminance of the central square was measured with the photometer placed 1m from the monitor while the room illuminance was increased incrementally from 0 to 1, 2, 5, 10, 20, 30, 40, and 50 lux. The central square luminance was varied from 0% to 20% of the maximum luminance in steps of 5%. The maximum monitor luminance used was 240 cd/m^2, and the minimum was 0.01 cd/m^2. These results are tabulated in Table 1 and depicted graphically in Figures 2 and 3.

In a separate set of experiments, we increased the target luminance incrementally to the maximum value of 240 cd/m^2 and repeated the measurements as described above. At high target luminance values, we did not observe any significant changes in measured target luminance with varied room light illuminance from 0 to 50 lux and surrounding monitor luminance from 0% to 20% of the maximum value of 240 cd/m^2. Therefore, it became obvious that with increasing room light, the white level value remained the same; however, the black level luminance value as measured at eye level increased. This change was observed to be higher for lower values of surrounding monitor luminance.

These findings led us to believe that, with the white level (maximum brightness) remaining the same, an observer loses contrast at higher ambient light because of an increase in black level

Table 1. Results of the Black Target Luminance Reading (in cd/m²) at Different Surround Luminance and Room Illumination Levels

	Ambient Light (lux)								
Surround (of max.)	0	1	2	5	10	20	30	40	50
0	0.02	0.04	0.07	0.15	0.33	0.61	0.86	0.96	1.24
5	0.12	0.14	0.18	0.26	0.44	0.72	0.97	1.06	1.34
10	0.22	0.24	0.27	0.36	0.54	0.81	1.07	1.16	1.43
20	0.41	0.44	0.47	0.56	0.62	1.01	1.23	1.37	1.64

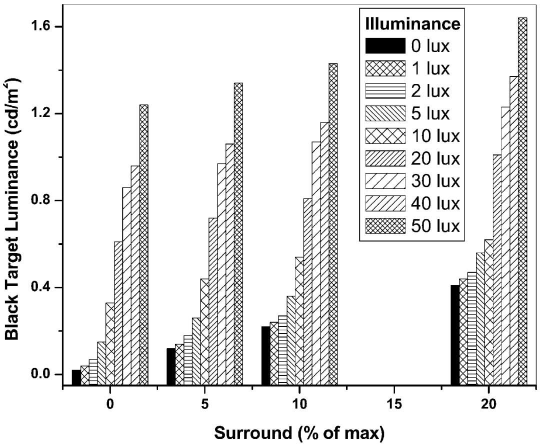

Fig 2. Change of Black Target Luminance with varying Surround at different room illuminace. Black Target Luminance increases sharply with increasing room illuminace particularly at low surround.

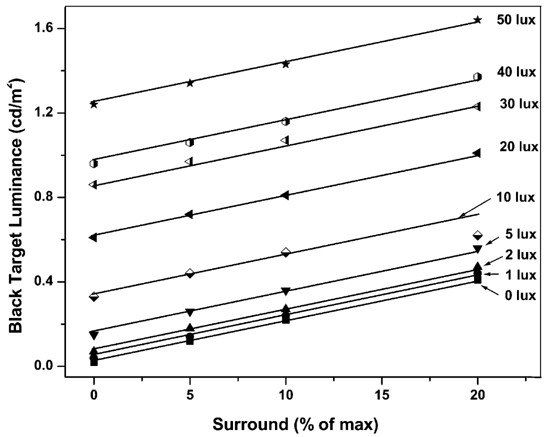

Fig 3. Sharp change in Black Target Luminance at lower surround is observed with increasing room illuminace. With white level virtually unaffected, contrast ratio falls more drastically at lower surround than higher surround with increasing room illuminace.

(minimum luminance) from the monitors. We have do observed that as the room illuminance at eye level is altered in steps from 0 lux to 50 lux, the measured luminance from a black target from the monitor increases by 100%. As we reduced the surrounding black level from 10%, the measured luminance from the black target exhibited a more drastic change with change of illuminance at eye level. Contrast ratio (white-to-black level luminance) changed from 24,000 (240/0.01) at 0 lux room illuminance to 226.41 (240/1.06) at 50 lux when the surrounding monitor luminance was set at 0% of the maximum of 240 cd/m^2, that is 0 cd/m^2. However, the contrast ratio changed from 600 (240/0.40) at 0 lux to 165.52 (240/1.45) at 50 lux room illuminance when the surround luminance of the monitor was set at 20% of the maximum of 240 cd/m^2, that is 48 cd/m^2.

These results show three interesting characteristics: (1) The contrast ratio is highest at 0 lux and at 0% surrounding monitor luminance. (2) The contrast ratio is lowest at 50 lux with a 20% surrounding monitor luminance. (3) The contrast ratio reduction is substantially greater for a 0% surround than for a 20% surround when the room illuminance is increased from 0 to 50 lux. For room illuminance levels up to 5 lux, the change in contrast ratio from 0% to 20% in surrounding monitor luminance is nearly the same. However, beyond that illuminance level, black target luminance increases rapidly with increasing room illuminance, indicating a sharp drop in contrast ratio.

The AAPM Task Group18[5], recommends that room illuminance be restricted to $I \leq (0.25\ L_{min})/Rd$, where L_{min} is the minimum dark level luminance and R_d is the diffuse reflection coefficient (cd/m^2/lux). Rewriting this equation, the minimum recommended monitor luminance is $L_{min} \geq 4\ R_d\ I$. From our data plotted in Figure 4, we calculated R_d from the

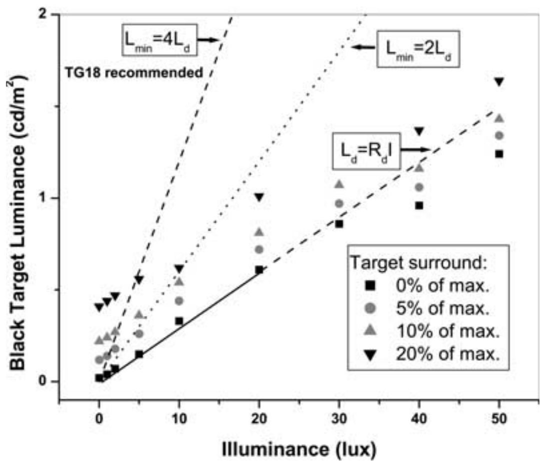

Fig 4. Change in Black Target Luminance with varying room Illuminance can be seen at different surrounds. From these results, TG 18 recommendation and alternative recommendation can be examined.

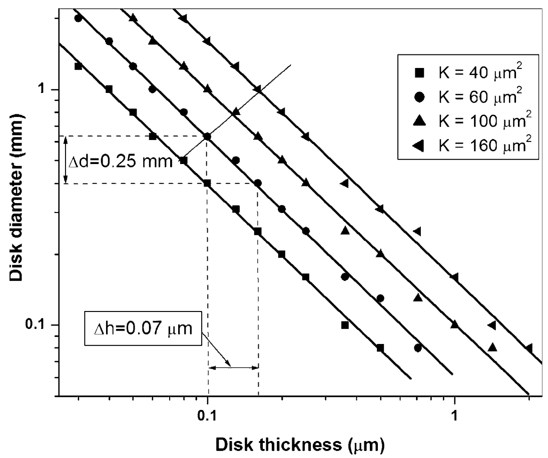

Fig 5. Methodology of CDMAM contrast detail phantom scoring can be observed graphically with lower K value representing better contrast resolution.

plot of target luminance at different room illuminance for 0% surround. The calculated value for R_d is 0.029 cd/m^2/lux, which agrees with the TG 18 listed value for R_d. Using this value, the L_{min} value was calculated from the TG 18 recommended expression $L_{min} \geq 4\ R_d\ I$. Calculated for different room illuminance, a theoretical line can be produced as shown in Figure 3, marked as TG 18 recommended. According to this line, the minimum monitor luminance should be greater than 2 cd/m^2 for 20 lux room light. In other words, to have a realistic minimum monitor luminance, room light should not be greater than 5 lux. From the expression of $I < 0.25\ L_{min}/R_d$, the TG 18 recommendation for a value of 0.29 cd/m^2/lux (in our case) with L_{min} of 1 cd/m^2, is that I should be less than 9 lux. For lower L_{min} values, say 0.5, I should be less than 5 lux. However, the German Standards Institution[13] (DIN 6868-57-2001) recommends that room illuminance be calculated as, $I < 0.5\ L_{min}/R_d$. This expression appears to provide a more realistic value for L_{min}, as shown by another theoretical curve constructed from our data, and based on this recommendation. This recommendation also provides a more realistic value of ~15 lux maximum room illuminance for the L_{min} value of 1 cd/m^2.

To investigate the effect of the observed loss in contrast ratio on image quality, in the second part of the experiment we imaged a CDMAM contrast-detail phantom using a GE Senographe 2000 D FFDM system. Technique factors of 26 kV, 50 mAs with a molybdenum filter and molybdenum targets were used to image the phantom. The phantom has a six, 1 cm Lucite sheet on a 15 cm × 23 cm × 0.5 mm aluminum plate with contrast detail inserts of 205 cells, each with two gold disks. Disk diameter logarithmically scales from 0.10 to 0.80 mm, and disk thickness logarithmically scales from 0.05 to 1.6 μm. The product of diameter and thickness is the same for all just-visible disks for a given column of disks. At different ambient room light levels, we measured illuminance at eye level and scored phantom images displayed on the monitors. Five observers participated in this study and all of them noted that ability to discern low-contrast objects decreases as the ambient room light increases. We also scored this phantom image at varying levels of surrounding monitor luminance.

Figure 5 shows an ideal reading from a CDMAM[14] phantom. Image quality parameters can be described by K, the product of diameter and thickness of just-visible disks. The lower the value of K, the higher the quality of the reading[15] in terms of image contrast. ΔK is the difference between the readings from one phantom object column to another. A cross-cut drawn through the parallel lines of different K values from 40 to 160 μm^2 shows that ΔK be-

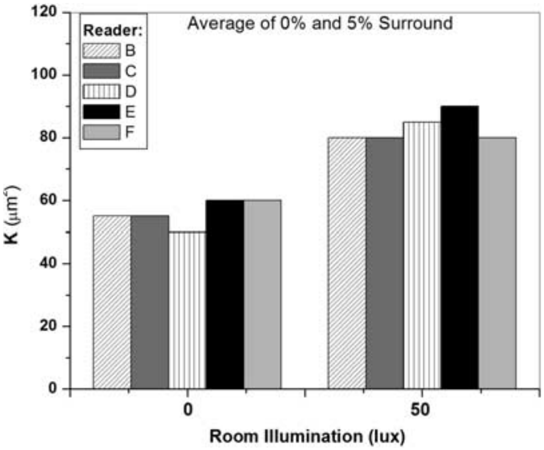

Fig 6. Readings of five readers are seen at average readings of 0 and 5% surrounds. Evidently, higher room Illumination of 50 lux show contrast degradations.

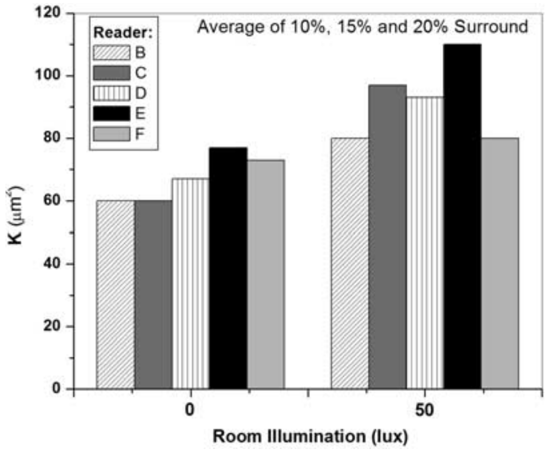

Fig 7. Readings of five readers are seen at average readings of 10, 15 and 20% surrounds. Again higher room Illumination of 50 lux show contrast degradations. But the change is less drastic than at lower monitor surrounds.

tween the two object readings between the two lines within the cross-cut.

Figures 6 and 7 show the actual CDMAM readings recorded by five different readers grouped at two different monitor surrounds, 0%–5% and 10%–20%, and at two different room light illuminances, 0 and 50 lux. Evidently, for a 0%–5% surround, the average K value changes from 50 at 0 lux to 90 at 50 lux, indicating a change of 1.8. For higher surrounds the degree of change is lower, from average K value of 70 to 90 as room illuminance is changed form 0 to 50 lux. Actual image quality comparison using a contrast-detail phantom agrees with our view that the contrast loss is lower for higher surrounding luminance with the same increase of room illuminance. Once again, the phantom scores and the lower K value at lower surrounding luminance confirm that at lower surrounding luminance and low room illuminance contrast is highest. Because the effect of room illuminance is much more drastic at lower percent surrounding luminance, and because it is not practical to interpret soft copy at 0 lux and to maintain this strict room illuminance value, it may be advisable to use higher surround luminance and room illuminance $>$ 0 lux.

Figure 8 summarizes the observer performance shown in Figures 6 and 7 in terms of K values at low and high illuminance of 0 and 50 lux. All five readers participating in this study

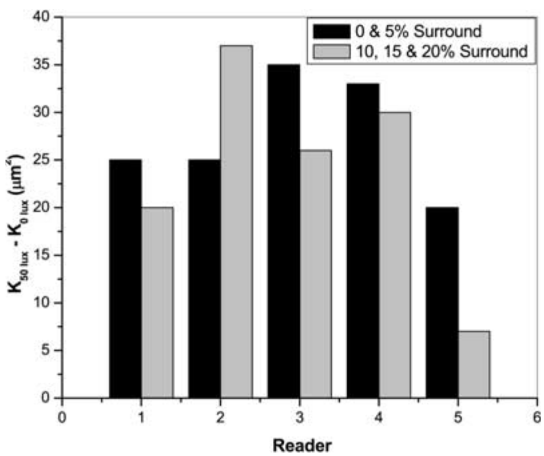

Fig 8. Increase in K value (decrease in contrast resolution) of all five readers readings are observed as room illumination is increased from 0 to 50 lux. Except for one observer, the increase is more drastic at lower surrounds.

exhibited remarkable degradation (increase in K value between 0 and 50 lux) in their phantom reading performance as illuminance was increased from 0 to 50 lux. Four of the five readers experienced this change more at the lower surround luminance of 0% and 5% of the maximum luminance, as shown by the darker shade in Figure 8. In general, our data indicate that 15%–20% surrounding monitor luminance and room illuminance under 15 lux provides an acceptable practical setting where degradation of image quality is not significant and will not risk misinterpretation and misdiagnosis.

SUMMARY AND CONCLUSION

We have observed that room illuminance affects the intensity ratio of maximum to minimum monitor luminance [by enhancing black level due to diffuse room illuminance.] The consequent loss in contrast ratio causes image contrast degradation. Even though a high contrast ratio is achieved when very low monitor surround luminance of 0%–5% of the maximum is used at low ambient light of 5 lux or less, an increase in room light illuminance can drastically reduce image contrast. It is therefore practical to use a 15% to 20% surround of maximum monitor luminance. With room illuminance of $I < 0.5\ L_{min}/Rd$, the ambient room illuminance should be maintained within 15 lux for a L_{min} value of 1 cd/m^2 and less for lower L_{min} values.

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REFERENCES

1. Chakrabarti, K, Thomas, JA, Kaczmarek, RV, et al: Optimization of viewing conditions and phantom image quality evaluations on GE DMR and full-field digital mammography system. J Digit Imaging 13(suppl):226-227, 2000

2. Waynant, RW, Chakrabarti, K, Kaczmarek, RV: Testing optimum of viewing conditions for mammographic displays. J Digit Imaging 12(suppl):209-210, 1999

3. Waynant, RW, Chakrabarti, K, Kaczmarek, RV: Improved sensitivity and specificity of mammograms by producing uniform luminance from viewboxes. J Digit Imaging 11(suppl):189-191, 1998

4. Task Group 18, American Association of Physicists in Medicine: Assessment of display performance for medical imaging systems.

5. National Electrical Manufacturers Association: Digital Imaging and Communications in Medicine (DICOM), Part 14: Grayscale Standard Display Function, 2000

6. Flynn, MJ, Badano, A: Image quality degradation by light scattering in display devices. J Digit Imaging 12:50-59, 1999

7. Roehrig, H, Krupinski, EA, Furukawa, T: Evaluation of a flat CRT monitor for use in radiology. J Digit Imaging 14:142-148, 2001

8. Haak, R, Wicht, MJ, Hellmich, M, et al: Influence of room lighting on grey-scale perception with a CRT- and a TFT monitor display. Dentomaxillofac Radiol 31:193-197, 2002

9. Hemminger, BM, Dillon, AW, Johnston, RE, et al: Effect of display luminance on the feature detection rates of masses in mammograms. Med Phys 26:2266-2272, 1999

10. Wang, J, Anderson, J, Lane, T, et al: Contrast-detail characteristic evaluations of several display devices. J Digit Imaging 13:162-167, 2000

11. Mertelmeier, T: Why and how is soft copy reading possible in clinical practice? J Digit Imaging 12:3-11, 1999

12. Cederberg, RA, Frederiksen, NL, Benson, BW, et al: Effect of different background lighting conditions on diagnostic performance of digital and film images. Dentomaxillofac Radiol 27:293-297, 1998

13. DIN 6868-57-2001: Image quality assurance in x-ray diagnostics: acceptance testing for image display devices. The German Standards Institution. Deutsches Institut für Normung e.V., February 2001

14. Bijkerk, KP, Lindeijer, JM, Thijssen, MA: The CDMAM-Phantom: a contrast-detail phantom specifically for mammography. Radiology 185:395, 1992

15. Suryanarayanan, S, Karellas, A, Vedantham, S, et al: Flat-panel digital mammography system: contrast-detail comparison between screen-film radiographs and hard-copy images. Radiology 225:801-807, 2002